UNCERTAINTY: THE CHALLENGE FOR POLICY ANALYSIS IN THE 21st CENTURY

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    shows they are needed. New policy analysis tools based on massive
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UNCERTAINTY: THE CHALLENGE FOR POLICY ANALYSIS IN THE 21ST CENTURY*

Warren E. Walker

November 2000

* Lecture presented on November 29, 2000 at Delft University of Technology on the occasion of the inauguration of the author as Professor of Policy Analysis and Decision Support Systems in the Faculty of Technology, Policy, and Management.

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ABSTRACT

The world in which governments must make policy is changing rapidly in unpredictable ways. Changes in information and communication technologies are eroding national borders and creating global markets. The relationship between the public and private sectors is changing. Furthermore, because of the globalization of issues and the interrelationships among systems, the consequences of making wrong policy decisions are becoming more serious – even catastrophic. What do these developments imply for policymaking and policy analysis? This talk suggests that a new policymaking paradigm and new tools for performing policy analysis are needed that will help governments to deal with uncertainty in policy formulation and implementation. The proposed paradigm, called *adaptive policymaking*, provides a flexible and rapid response to changing circumstances and builds in a plan for learning over time as part of the decisionmaking process. An adaptive policy would take those actions now that cannot be deferred, prepare to take actions that may later become necessary, monitor changes in the world, and take actions when the monitoring process shows they are needed. New policy analysis tools based on massive computing can be used by policy analysts to support the formulation of adaptive policies.

I. INTRODUCTION

I grew up in the United States in the middle of the 20th century. The 1950s were very conservative times in the United States. World War II was over, the country was experiencing unprecedented economic growth and prosperity. Industry began to mass-produce an immense variety of new goods and technological gadgets to provide the post-war generation with comfort and entertainment. Television came into its own. The TV dinner epitomized the lifestyle. And gas-guzzling automobiles with shiny chrome grilles epitomized the culture.

The Cold War was on. The military knew where the next war would be fought – in the Fulda Gap, along the Elbe, between East Germany and West Germany. So, all of the West's military planning was focused on preventing this specific next war, or on winning it. It would be hard to overestimate the amount of time and resources that were devoted to analyzing this single scenario. Similarly, corporate strategic planning was based on stability in the environment. RCA spent almost 10 years developing the first commercially available television set. Du Pont worked for 12 years to get nylon into production.

These were, indeed, simpler, stable times. People could make long-term plans for their lives. Corporations offered well-defined career paths; employees could plan on lifetime jobs with a single company. Defense planning focused on a single scenario, policymakers could put into place long-term policies with expectations that they would be long-lasting, and policy analysts could use predictive models to perform ''what-if' analyses, and talk realistically about making 'optimal' decisions.

II. PROBLEM STATEMENT

This well-ordered, stable environment began to change dramatically in the late 1960s. Some ascribe this change to the Beatles; some to the Vietnam war. I was in college during this transitional period. Bob Dylan told us "the times they are a-changing" – they were, and they have continued to do so, at what seems to be an accelerating rate.

Rapid advances in information technology have been the catalysts for many of these changes. The power of computers has been doubling every 18 months, and the amount of traffic being carried over the Internet has been doubling every 100 days. The cost of a telephone call from the United States to London *declined* by 90 percent in the last ten years, during which time the consumer price index *rose* by over 40 percent. Such developments have led to a sea change in the structure of human society, the nature of business and industry, and the role of government.

The economy is now a global economy. For a significant and growing portion of economic activity, distance no longer determines the boundaries of sales markets, the set of competitors, or even labor markets. In the past, white-collar jobs in traditional service industries were located near a company's head office. Now, such jobs can be competed for by any country in the world that has a decent telecommunications system and an appropriately skilled labor force. National boundaries make little difference to corporations or to financial markets, and markets can be quite fickle. Starbucks is driving local cappuccino shops out of business in Italy. Trillions of dollars flow around the world every day. Nations are powerless to fight such strong market forces.

Given an interlinked global economy and powerful market forces, how does a national government protect its own national interests? Countries have long wielded power and control over what went on within their borders. (A physical reminder of this power is that whatever entered the country was monitored by customs officers at borders and airports.) Cyberspace is eroding those borders. Intellectual properties flow freely across the Internet, knowing no borders. It is next to impossible for a nation to monitor them, much less block or levy taxes on them. Not only is internal monitoring and control becoming more difficult, but what happens externally now has an increasing influence on what happens internally. For example, in the past, companies could focus attention on local or national markets and governments could focus on their own economies. Success within these borders was normally sufficient for survival, and, indeed, for prosperity. This is no longer true.

Furthermore, because of the globalization of issues and the interrelationships among systems, the consequences of making wrong decisions have become more serious – even catastrophic. The economic success of countries in Euroland is dependent on the decisions made by a few persons at the European Central Bank. Every day we hear dire warnings about the possible negative effects of introducing genetically modified organisms into our food chain. And I don't need to tell you what the consequences of global warming might be for the Netherlands. The real problem in most of these potentially catastrophic situations is that scientific knowledge has not yet advanced sufficiently to offer definitive answers. But policy decisions have to be made – and are being made – about these issues.

What do these developments imply for policymaking and policy analysis? I believe that they imply the need for a new policymaking paradigm and new tools for performing policy

analysis that will enable governments to deal with uncertainty in policy formulation and implementation. I will discuss these implications in the remainder of this talk.

III. TRADITIONAL POLICY ANALYSIS

First, for those of you who are unfamiliar with public policy analysis, I will present a very short explanation of traditional policy analysis and how it has developed and changed over the past half-century to respond to changes in government and society. Policy analysis is a rational, systematic approach to making policy choices in the public sector. It supports policymakers in identifying policies that are cost-effective and that would help them to achieve their policy goals and objectives. I see policy analysis as a bridge between the scientific community and the policy community. The policy community often suffers because so little of what goes on in the scientific community is made understandable and accessible to it. Policy analysts act as translators and bridges between these two communities.

The traditional policy analysis process generates information on the consequences that would follow the adoption of various policies. (This is sometimes referred to as "what if" analysis.) It uses a variety of tools to develop this information and to present it to the parties involved in the policymaking process in a manner that helps them come to a decision. (For a description of the traditional policy analysis process, and an example of its application to a problem regarding the growth of air transport in the Netherlands, see [Walker, 2000].)

Policy analysis has its roots in a variety of scientific, engineering, and applied mathematics disciplines. It is not a specific methodology, but it makes use of a variety of methodologies in order to solve specific public policy problems. It evolved from operations research (in the late 1940s and early 1950s) through systems analysis (in the late 1950s and early 1960s) to policy analysis as a result of problem-oriented work for governments carried out at the RAND Corporation and other applied research organizations in the 1960s and 1970s. In the beginning, operations research techniques were applied to problems in which there were few parameters and a clearly defined single objective function to be optimized (e.g., aircraft design and the placement of radar installations). Gradually, the problems being analyzed became broader and the contexts more complex. Health, housing, transportation, and criminal justice policies were being analyzed. Single objectives (e.g., cost minimization or single variable performance maximization) were replaced by the need to consider tradeoffs among multiple (and conflicting) objectives (e.g., the impacts on health, the economy, and the environment, and the distributional impacts on different social or economic groups). Non-quantifiable and subjective considerations had to be considered in the analysis. Optimization was replaced by what Herb Simon (1969, pp. 64-65) called *satisficing*. He defined *satisficing* to mean finding an acceptable or satisfactory solution to a problem instead of an optimal solution. He said that satisficing was necessary because "in the real world we usually do not have a choice between satisfactory and optimal solutions, for we only rarely have a method of finding the optimum."

The broadening of problems and contexts led to a broadening of the disciplinary expertise required to perform policy analysis. The pioneers of policy analysis focused on military systems and were primarily physical scientists, mathematicians, and engineers. However, in order to deal with social problems, such as health and housing, social and behavioral scientists were needed. Each of these added disciplines brought new perspectives and new tools that are being used to improve and enrich the way public policies are identified, discussed, evaluated, chosen, and implemented.

Policy analysts have also expanded their focus well beyond the analysis of alternative policies to consider the entire policymaking process. It has been increasingly realized that the appropriate involvement of citizens and stakeholder groups in the problem-solving process can profoundly affect policy outcomes and popular support for those outcomes.

Furthermore, because of the need to deal with problems in our rapidly changing, complex, unpredictable world, uncertainty has become an increasingly important element in the analysis. There are many types of uncertainties that policy analysts (and policymakers) have to deal with – e.g., uncertainty about model form, uncertainty about the values of a model's parameters, and uncertainty about underlying probability distributions. Mathematicians, statisticians, modelers, and others have devoted a great deal of time and effort to most of these types, and have developed effective tools for dealing with them.[1] But, today I want to focus on a type of uncertainty that I call *structural uncertainty,* for which we have developed few tools. Structural uncertainty relates to the future structural elements of the world that are relevant for making policy, but are unknown and unknowable at the time of the analysis – for example, which countries will be most powerful in 2030, how will the population be distributed between cities and outlying areas, how will the climate change? The answers for 2030 will be known with certainty in 2030 – but will remain uncertain until then. As we get closer to 2030, the uncertainties will decrease. But, decisions have to be made in the face of structural uncertainty. For example, because of long lead times, we need to be thinking now about infrastructure changes to water management systems and transport systems that will be able to handle the problems to be faced in 2030. How can this be done?

IV. TRADITIONAL WAYS OF DEALING WITH UNCERTAINTY

Up until now, decisionmakers have dealt with structural uncertainty in one of two ways. The first (and most common) is to ignore it – to overlook it or act as if it is not there. An implicit assumption is made that the future world will be structurally more or less the same as the current world – perhaps more populated, richer, dirtier – but, essentially the same. Of course, this does not solve the uncertainty problem. It merely sweeps it under the rug, and can have serious consequences. For example, as discussed in a paper by de Neufville [2000], the telephone company of France was a pioneer in the use of on-line interactive telecommunications. It committed itself, on the basis of the most careful analyses, to the development of the Minitel system. But, it failed to build in the capability to change as the world changed – to expand to more advanced platforms using improved technologies for the system. This resulted in a network that is now virtually obsolete in the Internet environment, and that cannot practically be adapted to the new technical realities. It is a dinosaur less than 20 years after its initiation.

The second approach to dealing with structural uncertainty is more enlightened. It corresponds to the current policymaking paradigm and forms the basis for traditional 'what-if' policy analysis. It worked fairly well in the past when change was more gradual and predictable, there was less global competition, and the consequences of being wrong were smaller. The central assumption of this paradigm is that the future can be predicted well enough to identify policies that will produce favorable outcomes in one or more specific plausible future worlds. The future worlds are called *scenarios.* Policy analysts use best-estimate models (based on the most up-to-date scientific knowledge) to examine the consequences that would follow from the implementation of each of several possible policies

[1] See, for example, [Cooke, 1991] and [Morgan and Henrion, 1990].

in each scenario. The 'best' policy is the one that produces the most favorable outcomes across the scenarios. (Such a policy is called a *robust* policy.) The problem with this approach is that the resulting policy is best for specific scenarios that are fairly certain *not* to occur, since any given scenario has a probability zero of actually occurring. More important, the resulting policy has implications for the future that actually occurs that were probably not examined in the course of the analysis and that are generally not revisited as the future unfolds.

This approach has had its successes in the past and can work quite well – in fact, its popularity can be traced to its success in helping the Shell Oil Company handle the oil crisis in the early 1970s. However, if a policy is based on a variety of assumptions about the future and some of those assumptions turn out to be wrong, the negative consequences can be as bad as if structural uncertainty had been totally ignored. Consider the recent case of planning for the future of Schiphol Airport. In 1995, after a two-year multi-phased deliberative process known as "physical planning key decision Schiphol" (PKB Schiphol), some major decisions were made by the Dutch Parliament that were intended to guide the growth of civil aviation in the Netherlands to the year 2015.

One of the outcomes of the PKB-Schiphol process was the decision to constrain the number of passengers at Schiphol to no more than 44 million passengers per year. This constraint was supposed to be more than enough to accommodate the most optimistic estimates of passenger growth until at least the year 2015. These limits will certainly be reached well before then. And the noise limits, also expected to be reached no sooner than 2015, were reached in 1999.

How did such a long, costly, and deliberate planning process do such a poor job in forecasting the growth in air traffic at Schiphol? The passenger and noise projections were based on passenger forecasts that were produced by a model developed by the Central Planning Bureau [Centraal Planbureau, 1992]. This model assumes that the number of passengers passing through Schiphol is directly related to the value of the Netherlands' Gross National Product (GNP). This assumption was based upon the fact that, up until the time the model was built, there had been a very close relationship between the GNP and the number of passengers passing through Schiphol.

Of course, no one knows with certainty what the GNP will be in 2015. So, the CPB developed three scenarios, each with a different value of GNP, which were then used to produce three forecasts of the number of passengers at Schiphol in 2015. The 44 million figure corresponds to the forecast based on the highest GNP growth rate of the three scenarios. The actual growth of GNP through 1999 was closest to the assumptions in the *low-growth* scenario. Nonetheless (as shown in Figure 1) the growth in the number of passengers during this period was significantly more than what was forecast using the assumptions from the *high-growth* scenario – called Balanced Growth.

What happened was that a number of trend breaks – unanticipated changes in the world of civil aviation – had occurred after the forecasts had been made. The forecasts had assumed that the future would be a continuation of the past. But, in fact, three factors that have little to do with GNP growth rates were responsible for the rapid growth of air traffic at Schiphol:

1. The growth of hub-and-spoke networks, with Schiphol becoming a hub airport for KLM, where it cross-connects transfer passengers whose destination is not Amsterdam, but some other KLM city. Most of the growth in passenger traffic through

Schiphol has come from an increase in the number of transfer passengers carried by KLM. (The transfer traffic at Schiphol grew from 27% in 1990 to 43% in 1998.)

2. A code-sharing alliance between KLM and Northwest Airlines, which feeds Northwest's European traffic through KLM, and therefore through Schiphol.
3. The European Union's decision to liberalize the air transport industry – to reduce national monopolies and increase competition among airlines. As a result of this decision, European airlines are facing competitive pressures that they did not have to face in the past, fares have fallen, and the demand for air travel has increased.

So, great care must be taken in developing and using scenarios to deal with structural uncertainty. It is absolutely crucial to consider trend break scenarios.

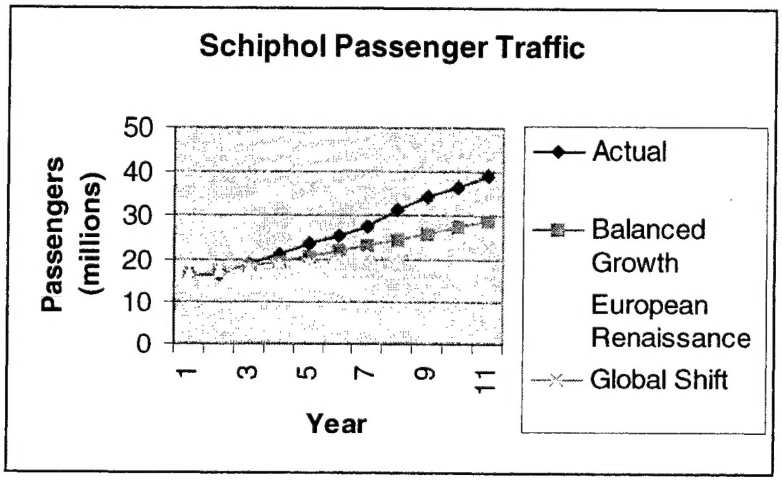

Figure1 – Actual and Projected Growth of Passenger Traffic at Schiphol Airport (1990-2000)

V. A NEW POLICYMAKING PARADIGM

I now turn to a third approach to dealing with structural uncertainty in policy formulation and implementation. This approach will require a new policymaking paradigm that will enable policymakers to react to rapidly changing situations. It is based upon the following line of reasoning:

(1) In this unpredictable rapidly changing world, it is almost impossible to identify robust policies -- fixed static policies that will perform well against all plausible futures.
(2) Over time, we gain information that resolves current structural uncertainties.
(3) Thus, the best policies will be adaptive (take those actions now that cannot be deferred; prepare to take actions that may later become necessary; monitor changes in the world and take actions when they are needed)

Most current policies do not explicitly provide for flexibility of response to changing circumstances, and do not incorporate a plan for learning over time as part of the decisionmaking process. When events occur that invalidate some of the underlying assumptions of a policy, the policy may remain unchanged for a long time or policymakers may scramble to quickly develop new policies. This approach is popularly called 'muddling through'. Adaptive policymaking and adaptive policies would explicitly recognize that

policies have to be adjusted as the world changes and as new information becomes available. The suggested 'adaptive' approach would create policies in advance that would respond to changes over time and that would make explicit provision for learning. As a result, the inevitable policy changes would become part of a larger, recognized process and would not have to be made repeatedly on an ad-hoc basis.

The concept of adaptation is easy to explain. It is analogous to the approach used in guiding a ship through a long ocean voyage. The goal – the end point – is set at the beginning of the journey. It remains constant. But, along the way, unpredictable storms and other traffic may interfere with the original trajectory. So, the policy – the specific route – is changed along the way. It is understood before the ship leaves port that some changes are likely to take place – and contingency plans may have already been formulated for some of the unpredictable events. The important thing is that the ultimate goal remains unchanged, and the policy actions implemented over time remain directed toward that goal. An adaptive policy would include a systematic method for monitoring the environment, gathering information, implementing pieces of the policy over time, and adjusting and re-adjusting to new circumstances. The policies themselves would be designed to be incremental, adaptive, and conditional.

Guiding the ship of state in this adaptive way may be revolutionary in many policy areas. But, it is already an accepted approach in some. For example, the U.S. Federal Open Market Committee and the European Central Bank set inflation targets and then change interest rates as conditions in the economy change. It is also rapidly becoming a guiding principle – indeed, a requirement for survival –in the private sector.

The analysis and choice of an adaptive policy would require a new process for policymaking that explicitly takes into account the uncertainties and dynamics of the problem being addressed. Two colleagues of mine and I have designed an approach to adaptive policymaking [Walker, Cave, and Rahman, 2001]. We divide the process into two phases: a 'thinking phase' and an 'implementation phase.' In the *thinking phase* the policy problem is formulated, the policy analysis is conducted, and the adaptive policy is specified, including the rules for its implementation. The *implementation phase* consists of the actual sequence of events and actions that represent the execution of the previously agreed upon adaptive policy. I will briefly present the process to you today as food for thought.

Thinking Phase

The first step in the adaptive policymaking process is a 'stage-setting' exercise designed to make policy goals explicit, develop a clear set of options, and construct a definition of policy success that makes operational sense. Successive steps in the process

- assemble the structure of the policy,
- identify key uncertainties,
- separate actions to be taken now from those that can or should be deferred until more information becomes available,
- develop signposts for monitoring changes in the world and triggers for contingency plans, and
- establish limits to the validity of the analysis that, once violated, should lead to a reassessment of the policy.

Figure 2 presents a diagrammatic view of the adaptive policymaking process. I will now walk you through the figure, describing the major steps in the process, illustrating them using a simplified, semi-hypothetical example.[2] Suppose that Schiphol Airport is running out of capacity and will not be able to accommodate much more growth. The central policy questions are: Should demand be accommodated? If so, how? If not, how best to limit it?

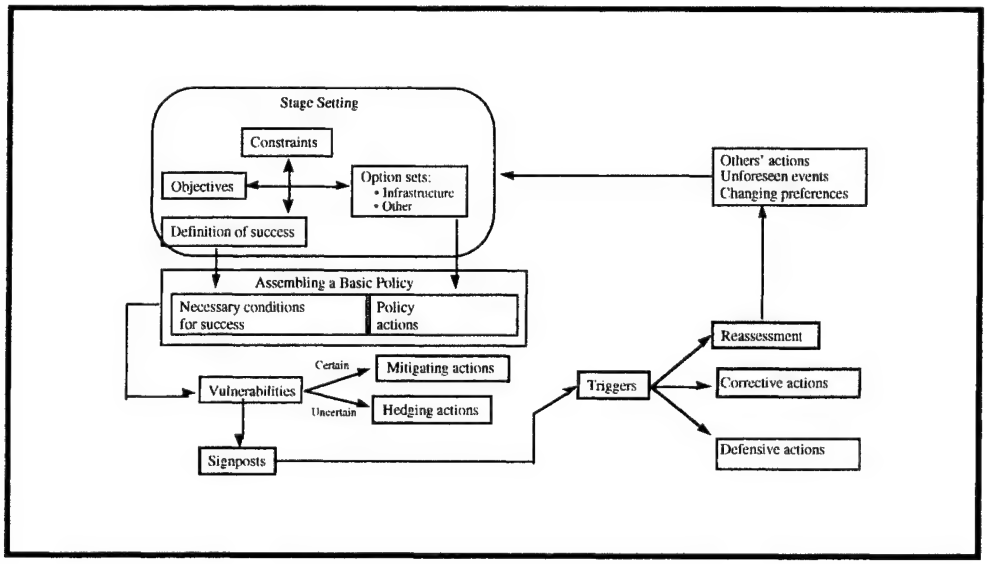

Figure 2 – The Adaptive Policymaking Process

Step 1: Setting the Stage

The activities in the rounded box in the upper-left corner of Fig. 1 constitute the stage-setting step in the policymaking process. In this step, the objectives, constraints, and available policy options are specified. This results in a definition of *success* and policy goals. For our example, suppose the goal was to maintain a major role for the Netherlands in civil aviation. The constraints could be those imposed by noise, emissions, economic, and other considerations. And the policy options could include various ways of increasing airport capacity and a host of measures for shaping demand, increasing efficiency, and mitigating the adverse side-effects of a growth in air transport.

Step 2: Assembling the Basic Policy

The next step is assembly of a basic policy – a well-defined initial policy together with the conditions that must be met in order for it to succeed. Continuing the example, a basic policy could be developed around the expansion of Schiphol Airport. It might include the building of a new runway, plus additional measures for reducing noise around the airport. Necessary conditions for success of this policy might be that the demand for air transport continues to increase, Schiphol maintains its market share compared to competing airports, and public (or political) acceptance of noise does not decrease.

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[2] For a more complete presentation of this example, see [RAND Europe, 1997].

Step 3: Specifying the Rest of the Policy

In the third step of the adaptive policymaking process, the necessary conditions for success and the details of the basic policy are combined in two sorts of forward-looking analyses, which result in a specification of the remaining pieces of the policy. One analysis is the identification of *vulnerabilities* – both uncertain and certain adverse consequences of the basic policy. These vulnerabilities can reduce acceptance of the policy to the point where its success is jeopardized. Two *uncertain* vulnerabilities of the basic policy in the Schiphol example might be that: KLM is acquired by another airline or goes bankrupt, leaving Schiphol without a hub airline, and accidents increase. In anticipation of an *uncertain vulnerability*, such as an increased risk of accidents, various *hedging actions* can be developed to diversify or reduce exposure or cushion the consequences. In our example these might include subsidizing accident insurance.

A *certain vulnerability* of the basic policy would be an increase in noise around Schiphol from a growth in air transport. Associated with the certain vulnerabilities are *mitigating actions* to be put in place immediately. These might include subsidizing sound insulation or creating 'noise markets.'

The second analysis is the translation of the necessary conditions for success into *signposts* that should be monitored in order to be certain that the underlying analysis remains valid, that implementation is proceeding on schedule and according to expectations, and that necessary policy corrections or additional actions are taken in a timely and effective manner. The identification of signposts does not call for immediate implementation of any direct policy actions. But once signposts are identified, efforts must be initiated to collect and monitor the necessary information. Critical values of the signpost variables, called *triggers*, are specified in this step. These will lead to the implementation of appropriate contingency plans, which should also be specified in this step. Signposts in the Schiphol example might include monitoring the growth of demand for air transport and monitoring the health of KLM (e.g., its market share and profitability). Slower than expected growth in demand might trigger a delay in the expansion of Schiphol. If KLM shows signs of failing, actions might be taken to prop it up or to attract another hub airline to Schiphol. In line with the idea of signposts and triggers, Mr. John-Hugh Rees of the European Commission Directorate General for Transport and Energy recently called for a new approach to collecting and using statistical information for decisionmaking. In particular he said "there will ... be an increasing need for rapidly available indicators that flag . . . changes that need the early attention of policymakers" [Rees, 2000].

Implementation Phase

Once the policy -- including signposts, triggers, mitigating actions, etc.-- is agreed upon, we are in the *implementation phase*. In this phase, events unfold and signpost information is collected. The adaptive policymaking process (as distinct from the adaptive policy itself) is suspended until a trigger event is reached.

Once the policy is agreed upon, we are in the *implementation phase*. In this phase, events unfold and signpost information is collected. The adaptive policymaking process (as distinct from the adaptive policy itself) is suspended until a trigger event is reached.

The response to a trigger event depends on the nature of the alarm. Many contingencies will have been foreseen in the original plan. As long as the basic policy, objectives, and constraints remain in place, these responses can be characterized as *defensive actions* or *corrective actions*. In our example, a major air disaster may overwhelm the hedging and

mitigating provisions, and lead to widespread dissatisfaction. The basic policy could then be defended by publicizing impending safety improvements, or corrected by scaling back expansion plans. If the trigger is slower than expected demand growth, some combination of reduction in the planned expansion or direct demand subsidies might be employed.

Under some circumstances, neither defensive nor corrective actions will suffice. For instance, there may be major changes in stakeholders' objectives, extremely large shocks to signpost information (e.g., a collapse of demand, runaway growth in demand, rapid growth in regional air traffic), or significant unforeseen actions by other players (e.g., a large cooperative expansion of Charles de Gaulle and Berlin airports). In such cases, the policy should be re-examined in its entirety. The conditions triggering a reassessment should be stated explicitly as part of the original policy (just as the conditions for corrective and defensive actions are part of the policy).[3]

This means restarting the policymaking process. But the process would not have to be started 'from scratch.' When the policy is reassessed, much more will be known about the world and the identities, motivations, and capabilities of other key players. Also, many aspects of the policy will already be in place and more will be known about the effects of the initial policies. Finally, participants in the process are likely to have a significant collective commitment to the process as a whole.

To sum up, adaptive policy analysis looks both from the present to the future and from the future to the present, in order to develop ways of comparing where we are going to where we would like to go. It views uncertainty as something to be qualitatively understood in order to manage the timing of critical decisions and to develop robust policies. And it is continuously making use of new information to resolve the original uncertainties over time.

IV. WORKING WITH THE NEW POLICYMAKING PARADIGM

Developing and implementing adaptive policies will not be easy. There are significant legal, political, and analytic barriers to be overcome. The legal and political barriers are likely to be the hardest to overcome. Existing laws have been built up over the years to support the current approach to policymaking and policy execution. The organization and operation of existing institutions, both governmental and non-governmental, are based on the current paradigm. Even if there were overwhelming support for the new paradigm, it could not be operationalized overnight, but would require the efforts of large numbers of experts from a variety of disciplines. Nevertheless, it should be easier to implement in a country like the Netherlands, whose government is based on consensus and stability, than in the United States, where a new government is often inclined to reverse the policies of its predecessor.

It will also require new analytical tools to help policy analysts identify good adaptive policies. I believe that recent increases in computing power can provide the basis for such tools. The growth in computer power over the past decade has resulted in computing capabilities that have never existed before. But, policy analysts have been slow to capitalize on these new capabilities. Our approaches are still based on methods that were developed when we had only limited computing power (e.g., using few scenarios or performing sensitivity analysis around a single base case). We policy modelers have always known that our models were

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[3] Davis, Gompert, and Kugler [1996] discuss a similar approach to adaptive policymaking. They call all but the reassessment 'operational adaptiveness' and the built in trigger for reassessment 'strategic adaptiveness'.

simplifications of reality – and not accurately predictive. They are often valid only under fairly restrictive assumptions. For most practical problems, many of these assumptions are not true. Similarly, as I've already shown, scenario-based approaches that focus on optimizing results for a given scenario may lead to serious negative consequences if the assumptions prove untrue. But, these tools have continued to be used (with improvements around their edges) because there were no viable alternatives.

The availability of cheap, powerful computing capability is now providing an alternative. The combination of computational speed, graphical display, and data handling make modern computers qualitatively different from the computers available in the 1950s when current policy analysis tools were developed. It is now becoming possible to explore the full implications for policy choices of structural uncertainties. Rather than limiting our analysis to a single 'best estimate' future or two or three scenarios we can explore the implications of millions of plausible future possibilities. The implications for policy analysis are profound. In particular, massive computing can supply the analytic support for the development of adaptive policies.

Research to develop modeling tools for harnessing this computer power and to develop new approaches to policy analysis based on these tools is currently being carried out by RAND researchers in California under the labels "exploratory modeling" [Bankes, 1993] and "exploratory analysis" [Davis and Hillestad, 2000]. The idea is to use the computer in the way that laboratories have long been used by physical scientists. Instead of physical experiments, we would make computational experiments. In fact, we would use computational power and graphical data visualization tools to run thousands or millions of computational experiments and make their results comprehensible.

In the process of constructing an exploratory computer model, a large number of assumptions are made. Running such a model reveals how the system would behave if those assumptions were correct. We would systematically explore how the outcomes of interest would change as a function of circumstances and assumptions, looking for answers to questions such as:

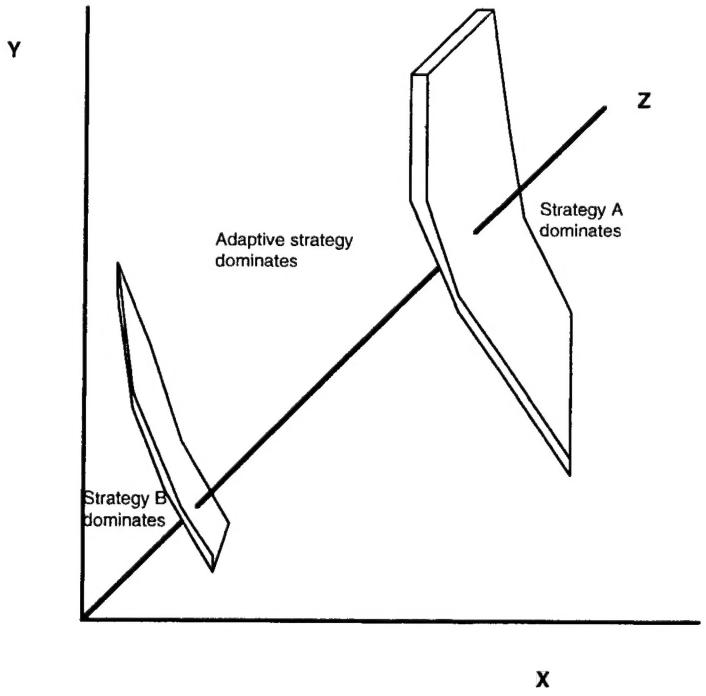
- Under what circumstances would the policymakers' goals be reached or success achieved?
- Under what circumstances would a policy fail or lead to negative consequences?
- What are the threshold values that would suggest changes in policy decisions?
- Under which of several adaptive strategies would long-term outcomes be acceptable for a wide range of futures?

For instance, this approach might be used to determine the conditions under which government investments in a specific transport infrastructure project could be justified, those for which they could not be justified, and those for which we are unable to tell. In a defense context, Davis [1994] described the use of "scenario space analysis" to explore the entire plausible scenario space. His objective was to increase the fraction of the scenario space in which certain stated objectives would be achieved, as opposed to identifying good policies for a few arbitrary scenarios.

In short, exploratory modeling and exploratory analysis could be used to support the type of adaptive policymaking I have described.

The concepts of exploratory modeling, exploratory policy analysis, and adaptive policy analysis may sound a bit vague and theoretical. In order to make them more concrete, let me

show how Lempert, Schlesinger, and Bankes [1996] have applied them in the context of devising a policy to respond to the (highly uncertain) situation of global warming. Figure 3 is a notional diagram that depicts the major conclusions from their study. It shows how the best strategies vary throughout a scenario space in which the key factors X, Y, and Z are unknown and uncontrollable. (X is the probability that extreme damages will result from an increase in temperature. Y is the probability that ways will be found to reduce the cost of abating greenhouse gas emissions. Z is the sensitivity of global temperature to an increase in greenhouse gases.) The question is, under what assumptions about X, Y, and Z would various strategies prove superior. Strategy A is one in which a lot is done right away to reduce carbon emissions. Strategy B is one of wait and see before doing anything. The adaptive strategy implements a series of actions as new information becomes available. The researchers explored the outcomes that could be expected in the complete (X, Y, Z) space (which involved about 40,000 runs of a series of four inter-linked models). They concluded that a strategy of do-a-lot-right-away would be wise only if one believed that the consequences of temperature change were likely to be quite severe (the top right corner of the figure). A strategy of wait-and-see would be wise only if the consequences of temperature change were likely to be quite modest (bottom left corner of the figure). But, in the very large region in between, an adaptive strategy that does more or less over time depending on the observed changes in global temperature is superior.



Source: Davis and Hillestad, 2000.

Figure 3 – The relative effectiveness of strategies in a 3-dimensionsal scenario space

Using these results, it would be possible to change the focus of the climate change policy debate. It is now a battle between those who favor investing heavily now to reduce carbon emissions and those who want to wait and see what might happen to climate in the future. The focus could be changed to devising an adaptive strategy that would increase or decrease the rate of investments in low-carbon methods over time as a function of signposts and triggers related to temperature change. This would change the frame surrounding the policy problem from one of resolving disagreements among scientists that are unresolvable given the current

state of knowledge to one of preparing for unpredictable contingencies. Within the new frame we could prepare an adaptive policy under which actions would be taken now that cannot be deferred and a system of signposts and triggers would be set up to monitor changes in the world and to take actions when needed. This would allow policymakers to make reasonable choices now about climate change policy without requiring accurate or widely accepted predictions of the future.

V. CONCLUDING REMARKS

Where does this all leave us?

We must be flexible, adaptive, open to change, but prepared for whatever the future might bring. There is no scenario I could have thought up that would have led to the trajectory of my life from its beginning to where I am now. From the Bronx in 1942, to Queens in 1951, to Cornell University in 1959, to Stanford University in 1964, back to Cornell in 1965, to the New York City-RAND Institute in 1970, to RAND Santa Monica in 1977, to RAND Europe in 1994, and now to a Professor in Delft. The world has been continuously changing around me. But, to an amazing extent, I have kept approximately my same professional goals – at least since my graduate school days in the early 1960s, when I decided to devote my life to applying mathematics and modeling to solving real world public policy problems. If anything, I have become more and more of a missionary for policy analysis. I am delighted that the seed of policy analysis that was planted in Delft when I was here in 1989 has blossomed into the faculty of Technology, Policy and Management, and that I have now been honored by an invitation to become a member of that faculty. I never dreamed of that outcome. But, I am grateful for it.

And so, to my bottom line message for policy analysis – and, in fact for all of us – as we begin the 21st century. It comes from a most unlikely source – a 19th century English naturalist named Charles Darwin. His answer to the question "who survives?" is:

Not the strongest,
not the most intelligent,
but those who are most responsive to change.

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